VOL. 12, NO. 4, FEBRUARY 2017 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

SPECTRUM OCCUPANCY MEASUREMENT: A CASE FOR COGNITIVE RADIO NETWORK IN LAGOS, NIGERIA

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ABSTRACT

The proliferation in technologies and with the recent introduction of new paradigm for wireless communication, the demand for wireless devices has increased drastically in recent years. This therefore, posed a major threat on the available frequency spectrum and as a result, an efficient method for the utilisation of the limited frequency spectrum is required. As the scarcity of frequency spectrum is a major problem in the telecommunication field, cognitive radio technology has been identified as a promising solution to this problem. Cognitive radio allows the opportunistic access of licensed bands by unlicensed users without causing harmful interference to the licensed user. There is a need to evaluate the utilisation level of the licensed bands in order to identify which frequency bands can be used for cognitive radio implementation. Nevertheless, spectrum measurement campaigns have been conducted mostly in USA and a few other locations around the world. In this paper, the results of the measurement campaign conducted in Ikeja, the capital city of Lagos, Nigeria covering the range of frequency 700 MHz up to 2.2 GHz is presented. The measurement results are analysed and compared to the frequency allocation table published by the Nigerian Communications Commission. The results obtained show that the frequency spectrum is underutilised and therefore a significant amount of spectrum is available for the future implementation of cognitive radio networks.

Keywords: cognitive radio; frequency spectrum; measurement campaign; wireless communications.

INTRODUCTION

Over the last couple of years, cognitive radio (CR) has received much attention from various research institutes. The concept of CR technology was first proposed by Mitola and Maguire [1] and has been identified to have a potential of resolving spectrum underutilisation issues arising from the growth in spectrum demand [2]. CR allows the opportunistic use of licensed frequency band by unlicensed users provided it does not cause any form of destructive interference with the licensed users. CR has also been defined as a wireless communication device that permits the sharing of spectrum over a wide range of frequency [3]. It is a software defined radio (SDR) based system that senses its operational radio environment and can dynamically and independently adjust its working parameters [4].

SDR devices allow the use of software for implementing hardware based components. The use of CR technology requires the knowledge of the available frequency bands. Consequently, a detailed study of the current spectrum occupancy is needed. This study involves the measurement of actual network statistics, which is an important step towards the dynamic access of the frequency spectrum and the deployment of CR for future networks. Previous research works have carried out spectral measurement campaigns for wide range of frequencies and specific licensed bands in order to ascertain the occupancy level of the allocated bands at different frequency, time and locations [5-10]. However, most of the existing measurements campaigns were conducted in the USA, thereby presenting results that analyses the American spectrum utilization.

Measurement campaigns have also been performed in few other locations around the globe. These include the campaigns conducted in the New Zealand [11], Germany [12], Spain [13] and Singapore [14]. To this end, the purpose is to provide a reliable source of information for understanding the spectrum utilisation rate. The results obtained from these measurement campaigns is valuable for the deployment of CR technology. However, to ensure a wide scale deployment of CR technology, results from measurements campaigns carried out in few geographical locations is not sufficient. This is because the different spectrum regulatory bodies and scenarios under which the measurement campaign was carried out must be considered. Hence the need to conduct spectrum measurement campaign for the present case study is vital. In this paper, the result from the spectrum measurement campaign conducted in Ikeja, the capital city of Lagos state in south western part of Nigeria is presented. The campaign was done in an indoor environment covering the frequency range of 80 MHz (Trunk radio services and GSM band) and 2.2 GHz (3G band).

The results and analysis of the measurement campaign is compared with the official spectrum allocation table provided by the Nigerian Communications Commission (NCC), the government regulatory body saddled with the responsibility of allocating frequency in Nigeria [15]. The rest of the paper is organized as follows. Section II illustrates a brief description of the equipment used to carry out the measurements, its configuration, the measurement location and the methodology followed during the measurement. Section III presents the analysis of the measurement results and highlights the potentials of

VOL. 12, NO. 4, FEBRUARY 2017 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

the CR based on the obtained results while Section IV concludes the paper.

MEASUREMENT METHODOLOGY

The description of the measurement methodology is an important part of any spectrum measurement campaign. Matheson [16] discussed various considerations in defining strategies and methodology while conducting spectrum measurement campaigns. The measurement was carried out for the whole day. Threshold values for all the application bands were determined by replacing the antenna with a matched load of 50 Ω. The choice of the measurement location was based on the fact that Lagos is the most populated state in Nigeria. According to the 2016 population review [17], Lagos is the most populous city in Africa with an estimated population of twenty-one million people. Ikeja is the capital and commercial hub of Lagos, supporting several industries and government agencies. The strategic nature of the chosen location enables us to effectively measure high traffic spectral activity.

Measurement equipment and configuration

The study was conducted using Aaronia AG HF-6065 V4 Spectrum analyzer. The Analyzer offers better functionality, features and specifications compared to other similar devices. It was controlled by a Personal Computer connected via a USB cable. A passive omnidirectional antenna with vertical polarization specified from 300-3000 MHz frequency range was used to carry out the measurement campaign. This is because multipath signals reach the antenna from different direction; hence the signal direction cannot be predetermined. The main features of the spectrum analyzer are shown in Table I.

Table-1. Features of Aaronia ag hf-6065 v4 spectrum analyzer [18].

Parameters	Value
RF frequency range	10 MHz to 6 GHz
Resolution (RBW)	3 kHz to 50 MHz
Interface	USB 2.0/1.1
Input	50 Ohm SMA RF-input (f)
Accuracy	+/- 2dB (typ.)
Max measurement range	-150 dBm (1Hz)
Lowest possible Sample Time	1mS

The measurement configuration parameters for the campaign are shown in Table-2. The measured frequency span of 1.5GHz was divided into eight continuous sub-band with scanning step size of 200 to 400 MHz. In each of the sub-band, more than 10000 traces were obtained. In order to achieve high resolution, sub-bands one to six was analyzed using resolution bandwidth of 200 kHz while sub-bands 7 and 8 was analysed using a resolution bandwidth of 1MHz. The above parameter was adjusted based on the predetermined bandwidth characteristics of the selected sub-bands.

Table-2. Configuration of spectrum analyzer used throughout the measurements.

Parameters	Value
Frequency bands	Sub-band 1: 700MHz - 900MHz Sub-band 2: 900MHz - 1100MHz Sub-band 3: 1100MHz - 1300MHz Sub-band 4: 1300MHz - 1500MHz Sub-band 5: 1500MHz - 1700MHz Sub-band 6: 1700MHz - 1900MHz Sub-band 7: 1900MHz - 2100MHz Sub-band 8: 2100MHz - 2200MHz
Frequency Span	700 MHz to 2200 MHz
Measurement Duration	24 hours
Resolution Bandwidth	200KHz (Sub-bands 1, 2, 3, 4, 5, 6) 1MHz (Sub-bands 7 and 8)
Sweep Time	Automatically Selected
DANL (Displayed Average Noise Level)	-135 dBm (1 Hz)

MEASUREMENT RESULTS AND ANALYSIS

Spectrum occupancy metrics

The statistics of spectrum occupancy is important for the spectrum regulatory body of any country. It is also known as duty cycle and it is handy in the frequency bands assignment and monitoring of their usage. It illustrates the degree to which the allocated frequency bands is been used. Several definitions for the spectrum occupancy in measurement campaigns can be found in the literature. However, the most widely accepted definition was given by Splauding and Hagn [19]. The authors defined Spectrum occupancy as the period which the value of the received signal power exceeds a power threshold level [19].

In this work, it will be sufficient to define spectrum occupancy as the period where the received power level for a given frequency band exceeds the decision threshold [20]. The decision threshold value is a vital information needed for accurate evaluation of spectrum occupancy and as such must be carefully chosen. A high value of the threshold results to having an underestimated spectrum occupancy details while a low value might result to having an overestimated spectrum

VOL. 12, NO. 4, FEBRUARY 2017 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

occupancy details. Previous research works suggest that the decision threshold value be kept at a certain Decibel (dB) power above the system noise of the measurement equipment. In this work, the decision threshold used was 10 dB above the system noise level as recommended by the ITU [21].

It is worth mentioning that the decision threshold used in this work is not constant, since the system noise increases varies with frequency. Energy detection (ED) technique was adopted among several other detection techniques because it does not require prior information of the transmitted signal. In the ED technique adopted, the received signal for a given frequency sub-band is compared to a predefined threshold value. If the value of signal power is above the threshold value, it means that the band is occupied by the primary user or licensed owner of the frequency band. Else, the frequency band is free and could be used for the implementation of CR networks. Finally, we calculated the spectrum occupancy on a frequency sub-band as the product of the average duty cycle and the channel bandwidth.

Spectrum occupancy analysis

In this section, details of the spectrum measurement campaign of the frequency bands allocated to different licensed users id presented. Table-3 summarizes the occupancy statistics by band.

Table-3. Average duty cycle analysis of spectrum occupancy.

Frequency range (MHz)	**Application & services**	**Utilized spectrum** (MHz)	**Average duty cycle**	
			%	**%**
700-1000	Trunk radio services and GSM band	148.5	49.5	
900-1300	GSM band	193.2	64.4	
1300-1700	Rural Telecoms and GSM bands	1.6	0.4	36.87
1700-1900	GSM, Oil coy and Satellite broadcast	7.4	3.7	
1900-2200	3G band	138.9	46.3	

The first band 700 to 1000 MHz is part of the 470–960 MHz band which is allocated analog TV [15]. This band has also been allocated to fixed applications, other trunk radio services and GSM links. A total of 300MHz frequency has been statically allocated for this band bit only 148.5MHz is presently utilized. This implies that the spectrum occupancy in the 700-1000 MHz band is 49.5 %. This is due to the fact that there are so many analog TV broadcasting station around Lagos metropolis. The next band is 900–1300 MHz has been allocated to for GSM bands according to Nigerian Communications Commission [15]. This band has an average duty cycle of 64.4%. This band has also been allocated to radio navigation satellite services. This band has the highest value for the average duty circle mainly because a lot of GSM of the traffic generated by the GSM users in Lagos. These two bands have average spectrum occupancy 49.5% and 64.4% respectively, which is quite high.

Table-4. Statistics of the underutilised spectrum.

Frequency range (MHz)	**Application & services**	**Under-utilized spectrum**	
		MHz	**%**
700-1000	Trunk radio services and GSM band	151.5	50.5
900-1300	GSM band	106.8	35.6
1300-1700	Rural Telecoms and GSM bands	398.4	99.6
1700-1900	GSM, Oil coy and Satellite broadcast	192.6	96.3
1900-2200	3G band	161.1	53.7

In Table-4, we present statistics showing the frequency bands and the percentage of underutilised spectrum for the bands under investigation. Figure 1 presents a chart showing the allocated spectrum, utilized spectrum, the underutilised spectrum for the different frequency bands.

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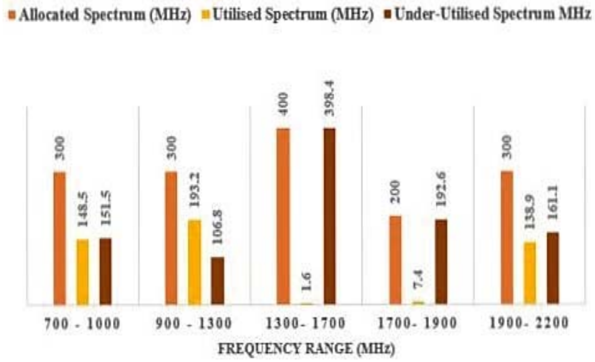

Figure-1. Allocated spectrum, utilized and underutilized spectrum statistics.

The next band is 1300-1700 MHz and 1700 - 1900 MHz has been allocated for fixed mobile radio location, space research, radio astronomy, digital audio broadcasting, mobile satellite and meteorological satellite. [15]. this two have a joint allocation 600MHz which is heavily underutilised. From our findings only 0.4% and 3.7% which makes up 1.6MHz and 7.4MHz respectively of the allocated 600MHz is utilized in this frequency band. These bands can be utilized for the implementation of CR networks given the amount of underutilised frequency band in this range. Lastly the 1900 - 2200 MHz band which has been allocated [15] for 3G mobile and fixed services was measured. Our findings showed that only 46.3% of the band is utilized. From the duty cycle analysis carried out, 53.7% corresponding to 161.1MHz of the 200MHz band allocated for this band is idle and can be fully utilized for CR networks.

Summary of measurement analysis

In this section, the summary and observations from the spectrum occupancy analysis id presented and Figure-2 graphically presents the band wise occupancy statistics.

Observations

a) The highest occupancy 64.4% was observed in the GSM 900 band.
b) Low spectral occupancy was recorded in the 1300-1700 MHz and 1700 - 1900 MHz bands allocated for fixed mobile radio location, space research, radio astronomy, digital audio broadcasting, mobile satellite and meteorological satellite.
c) The occupancy recorded by bands used in satellite services is low due to the signal path loss, and the inability of the measurement system to detect it.
d) The results obtained from the measurement campaign shows that the spectrum is not uniformly utilized. In some part, heavy utilization of the spectrum was recorded while some part of the spectrum recorded negligible utilisation results.

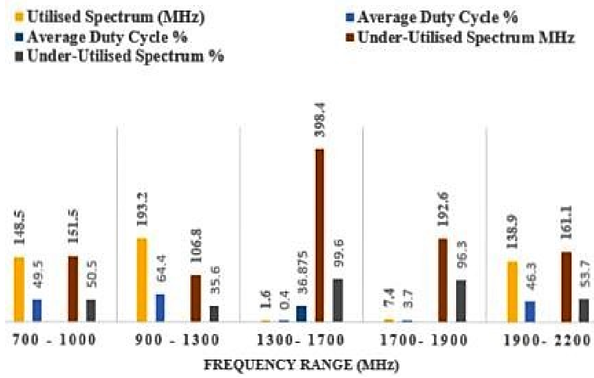

Figure-2. Summary and observations from the spectrum occupancy measurement results.

CONCLUSIONS

In this paper, we investigated spectrum occupancy level in the frequency span of 700-2200 MHz in an indoor environment in Ikeja, Lagos Nigeria. The measurement results obtained revealed that a significant amount of spectrum which has been allocated is being idle and therefore underutilised. As a result, this can be potentially used for the implementation of cognitive radio networks in the future. In addition, the authors proposed a future measurement campaigns in other environments with refined measurement methods to have better measurement set ups and a better model for cognitive radio deployment. These would enable a better understanding of the opportunistic spectrum utilisation and to identify the frequency bands that are most suitable for cognitive radio networks.

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